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HEATING

HEAT AND TEMPERATURE

Children's ideas about heat have been the subject of a lot of research and studies have taken place in many countries. Certain patterns emerge and it is clear that children have difficulty in understanding this area of science. Harris,[1] as reported by Hewson and Hamlyn,[2] suggests that the subject of heat is one of the most confused in science and that the source of this confusion centres on the use of words like 'heat', 'heat flow' and 'heat capacity'. Harris, referring to students' tendency to think of heat as a 'substance' which flows from place to place, claims that 'many students' conceptions of heat today are, on the whole, not very different from those of Lavoisier (1789), that is, they think calorically'. Indeed, many researchers have found that children think of heat as a substance, and Hewson and Hamlyn have drawn attention to language and cultural influences.

Erickson[3] reported that children think of heat as a 'type of subtle substance, like air, that is capable of flowing into and out of objects'. Other studies have observed a similar notion and that the 'substance' is often thought to flow or have fluid characteristics. Erickson noted that both cold and heat are often associated with air.

Engel Clough and Driver[4] report that pupils up to the age of 16 think of cold as 'an entity which, like heat, has the properties of a material substance'. It appears that children do not necessarily think of hot and cold as part of the same continuum. Rather, they perceive them as two different phenomena, with cold often being thought of as the opposite of heat.

Watts and Gilbert[5] found seven 'alternative frameworks' for thinking about heat which were commonly used by a group of 14- to 17-year-olds:

- conspicuous heat, in which heat is only associated with very hot bodies and large amounts of heat;
- dynamic heat, in which heat is associated with movement;
- motile heat, in which heat is seen as something which spreads out

from one place to another and as 'more insidious and fluid-like than direct (conspicuous) heat';

- normal heat, which is taken as body temperature and humans are seen as the standard for measuring heat;
- product heat, which is taken to be manufactured, deliberately contrived heat as distinct from natural heat;
- standard heat, in which any temperature above 'freezing' represents heat and in which cold is the opposite of heat and applies to any temperature below freezing;
- regional heat, which assumes a static model of heat occupying a particular area, and cooling is seen as a reduction of heat intensity.

Engel Clough and Driver note that certain 'facts' about heat such as 'heat rises', 'hot things expand' and 'heat travels through metals' are 'known' by children but they are not explained. (Erickson[3] reports that children who have an intuitive notion that heat makes things rise may use this to explain water expanding up a tube.)

Erickson reports that distinguishing between the concepts of heat and temperature was one of the most difficult tasks for children. They tend to view temperature as the mixture of heat and cold inside an object, or simply as a measure of the amount of heat possessed by that object, with no distinction between the intensity of heat and the amount of heat possessed. Many children think that the temperature of a body is related to its size, volume or the amount of stuff present. Children also think of temperature as a property of the material, their everyday experience of touching objects supporting a notion that some substances are naturally warmer or colder than others.

When considering pupils' ideas of the difference between 'heat' and 'temperature', Tiberghien[6] reports three categories of response:

- the idea that heat is hot, but temperature can be cold or hot: 'temperature – you can have something freezing, whereas heat – you tend to think of something being hot. Heat . . . it's the warm end of the scale'. (This view was more common among 10- to 12-year-olds.)
- the idea that there is no difference between heat and temperature: 'temperature is heat'. (This type of thinking was found in pupils from age 10–16.)
- the idea that temperature is a means of measuring heat: 'temperature – you can measure heat with, but heat is hot – you can feel heat'.

Tiberghien notes that children do not recognise temperature as a physical parameter that can describe the condition of a material. For them other criteria are more pertinent for describing materials.

There have been several studies of children's ideas about the resultant temperature when volumes of water at different temperatures are

mixed. When a quantity of cold water is mixed with an equal quantity of hot water children often say that the mixture will be 'warm'. However, if the initial temperatures of the water are given there are fewer correct answers. Driver and Russell,[7] studying 324 Malaysian and English pupils, found that over 50 per cent of 8- to 9-year-olds and 80 per cent of 13- to 14-year-olds gave correct qualitative judgements but less than 25 per cent of 13- to 14-year-olds predicted an average temperature when numerical values were introduced. They tended to add or subtract the two initial temperatures to find the final one. This pattern was also found by Stavy and Berkovitz[8] in their study of seventy-seven Israeli 9- to 10-year-olds.

Strauss and Stavy[9] report that, when considering the final temperature of a mixture of two beakers of cold water, children aged 4–6 often judged the temperature to be the same. However, older children, aged 5–8, often said that the water would be twice as cold because there was twice as much water. Older children, aged up to 12, again judged the water to have the same temperature as the separate beakers. To explain this, Strauss and Stavy suggest that the youngest children do not consider the amount of water when making their judgement, whereas older children do attend to the amount and judge the temperature as if it were an extensive physical quantity. The oldest children are able to differentiate between intensive and extensive quantities and make judgements accordingly, understanding that the temperature remains unchanged despite changes in the amount of water. Strauss and Stavy also found that children tended to make more correct predictions of temperature when equal amounts of hot and cold water were mixed, than when two equal amounts of cold water were mixed.

A study was carried out by Driver and Russell[7] in which children were shown a beaker of ice with a thermometer reading 0°C. Pupils were asked what would happen to the reading if more ice was added. The majority of the youngest children (aged 8) thought that the temperature would go up when the volume of ice was increased. The older children (aged up to 14) tended to think that the temperature would decrease when more ice was added.

In Appleton's study[10] of twenty-five Australian 8- to 11-year-olds, three children did not recognise a mercury-in-glass thermometer and did not know what it was used for. The majority of the remaining children either said that it told how hot or cold something was or that it told us the temperature of something. The children were asked to speculate on the likely temperatures of some water which had just boiled and of a cold drink with lots of ice in it. Most children seemed very uncertain in their suggestions and many may have simply guessed. Less than half gave an answer in the 0°C to 10°C range for the iced water and less than a quarter suggested a temperature in the 90°C to 100°C

range for the boiled water. One child thought that thermometers are 'used for measuring heat' only and therefore gave no temperature for the iced water. When asked how they thought the thermometer worked, roughly a third suggested that the thermometer 'was sensitive to heat', or that it was 'made to go to the right number'. Other suggestions involved pressure, pushing, or were concerned with heat rising. Appleton concluded that 'apparently simple and straightforward activities on temperature with this group of children were found to expose a high level of ignorance regarding relatively basic ideas about temperature and its measurement'.

ENERGY TRANSFER PROCESSES

Research into ideas about energy transfer has concentrated on heat conduction.

Erickson[3] investigated children's ideas about how the whole of a metal rod gets hot when only one end is heated. Children thought of heat accumulating in one spot and then overflowing to another part of the rod and they appeared to be attributing material properties to the heat.

From Engel's study[11] of children's ideas about the conduction of heat, it appears that children use different explanations in different situations. Considering spoons made of different substances and what they would feel like in a jug of hot water, many children explained the differences in terms of heat travelling through different materials at different rates. Explaining the differences experienced when they placed their hands on metal and plastic plates, children tended to refer to some observable property of the material or to suggest that metals let heat in or out more easily than other materials. Most children explained metal parts of a bike feeling colder than the plastic parts in terms of metal attracting or absorbing coldness.

Watts and Gilbert[5] report pupils' ideas about a metal bar which was heated at one end and cooled at the other. Pupils aged 13–17 referred to hot molecules moving along the bar to the cold end, where they cooled and stopped moving. The younger pupils also referred to cold molecules in the water and some suggested an exchange of hot molecules from the bar with cold molecules from the water.

Engel Clough and Driver[4] observed that pupils' answers were influenced by the direction of heat conduction in relation to the pupil. More children used the idea of heat moving towards, as opposed to away from, the hand. Children appeared to find it difficult to think of heat conduction when they felt a cold surface. This finding is supported by Brook *et al.*[12] who report that children seemed to think that the sensations of hotness and coldness are due to something leaving the hot or cold object and entering the body. Students in their sample of 300

15-year-olds thought of coldness being transferred to the person from the cold object, rather than heat being transferred away from the person to the object. The percentage of students showing an understanding of heat transfer fell from 15 per cent to 6 per cent when heat transfer was away from the body rather than towards it. It appears that very few students understood heat transfer in terms of the behaviour of particles: less than 5 per cent of the sample attempted to describe conduction in terms of particles and only a few of these used the accepted terms. Pupils appeared to be confused as to the heat transfer process in a given situation and conductors and insulators were seen as opposites, having no degrees of conducting ability.

Driver[13] reports that, athough older pupils (aged 11–16) who have been exposed to teaching about the kinetic-molecular theory of matter might attempt to explain phenomena such as conductivity in terms of particulate ideas, these were not used spontaneously by most children. When particle ideas were used there was a tendency to attribute macroscopic properties, such as melting or expanding, to the microscopic particles.

Engel Clough and Driver[4] report that, to explain different conductivities, students drew on the observable properties of the materials, such as hardness or thickness. In their 12-year-old group, 37 per cent referred to such properties in explaining why metal and plastic plates felt as though they were at different temperatures. Some children said that metals were colder substances than plastic. A third of the 12-year-olds explained the different temperatures of four spoons standing in a bowl of hot water in terms of different speeds of movement of heat. Many children referred to metals 'pulling in' heat or to heat being 'released' or 'let out easily' by metals. Five students in the sample suggested that heat did not penetrate metals and stayed on the surface therefore allowing the heat to be conducted well.